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MUSICAL EXPERIENCE AND TONAL SCALES IN THE RECOGNITION OF OCTAVE-SCRAMBLED MELODIES

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Octave-scrambled melodies, having their pitches randomly distributed over several octaves, are difficult to recognize. Such melodies do not preserve pitch-interval patterns of undistorted melodies, but only their sequence of chromas—that quality of pitch shared by tones an octave apart. In four experiments subjects heard chroma-only octave-scrambled melodies preceded by melody cues: unscrambled versions of either the target melody or a different melody. Subjects judged whether octave-scrambled target melodies were the same as or different from the cue melodies. Familiar melodies were easier to recognize than unfamiliar, and subjects performed just as well with familiar melodies when melody cues were replaced with tune titles. Unscrambled repetitions of tonal unfamiliar melodies were easier to recognize than atonal ones, especially for inexperienced subjects. Moderately experienced subjects found tonal (vs. atonal) octave-scrambled melodies easier to recognize, but inexperienced subjects found tonal and atonal equally difficult. This suggests that subjects encoded diatonic scale steps or chromas of cue melodies, and tested those encoded representations against chromas of comparison melodies. Experienced subjects were better than inexperienced at using the chroma information in octave-scrambled test melodies.

Distorting the pattern of pitch intervals makes a melody difficult to recognize. Two distortions of interval pattern that are especially disruptive are the rapid temporal interleaving of foreign notes between the notes of a target melody (Dowling, 1967, 1973) and the random distribution of the notes of a target melody among several different octaves (Deutsch, 1972). In neither case is the altered pattern immediately recognizable. However, Dowling demonstrated that with interleaved melodies the distorted melody can be recognized accurately if the listener knows what melody to listen for. Deutsch suggested that the same should be true for octave-scrambled melodies, and Experiments 1 and 2 below provide evidence validating Deutsch's suggestion. Theories of recognition of distorted melodies must deal with a two-pronged question posed by these results: Why do listeners have difficulty recognizing the distorted melody when it is presented without additional context, and yet find it relatively easy to recognize a target melody when informed of its identity.

Theories of melody recognition generally attempt to specify features of melodies that are important in perception and memory, and to describe the processing of those features in listener's performance of various tasks. Theories specify features on the assumption that certain aspects of a melody are psychologically more important than others. Listeners do not literally perceive and remember the acoustic waveform as a taperecorder might be said to do, but rather they abstract, interpret and store selected features of the sound pattern. Features that have been proposed as important to the recognition of a melody are (a) the ordered set of pitches, (b) the inferred set of pitches in the underlying tonal scale, (c) the ordered set of pitch intervals, (d) the pitch contour, or pattern of ups and downs (Dowling & Fujitani, 1971), and (e) the pattern of relative onset times of notes, or rhythmic contour (Monahan, 1983). Further, the sets of pitches in (a) and (b) can be thought of either as absolute and fixed, or as relative. For example, "Frére Jacques" can be characterized as starting with the pitches C, D, E, C (absolute), or do, re, mi, do (relative, using a "movable do"). "Frére Jacques" can also be described as starting on C in the *key* of C major (absolute), or as starting on the first degree ("do") of the major *mode.* Besides the distinction between absolute and relative descriptions of pitch, there is general agreement that the psychophysical representation of musical pitch has at least two dimensions: tone height or octave level, and chroma. *Tone height* refers to the dimension along which one pitch is simply higher or lower than another; while *chroma* refers to the quality shared by tones an octave apart in pitch (Idson & Massaro, 1978; Dowling, 1978a; Shepard, 1982). The chromas of pitches can be represented as lying around a circle. In a simple version of this pattern the pitches of the chromatic scale are arranged in a circle: C, C#, D, D#, E, F, F#, G, G#, A, A#, B, C. The chroma representation "C" that you reach after going around the circle is the same as the "C" with which you started. The chromatic similarity of tones an octave apart is often called *octave equivalence.*

Suggested Terms

In addition to absolute vs. relative specification of pitch levels and presence or absence of octave equivalence, whether a pitch is part of a tonal scale system is an important dimension for the psychological representation of

Table 1
Outline of Suggested Terms for Features of Musical Pitch

Pitch Reference	Octave Equivalence	Term	Related Process
NONTONAL PITCH MATERIAL			
Absolute	No	TONE HEIGHT	
	Yes	CHROMA	
Relative	No	PURE INTERVAL	
	Yes	INTERVAL + OCTAVE EQUIVALENCE	
TONAL PITCH MATERIAL			
Absolute	No	TONAL CHROMA + OCTAVE LEVEL	Could be coded as intervals within a key—fixed do diatonic system
	Yes	TONAL CHROMA	Basis for absolute pitch
Relative	No	SCALE STEP	Could be coded as abstract interval set—movable do diatonic system
	Yes	SCALE FUNCTION	Could involve dynamic tendencies in scale

pitches (Dowling, 1978a, 1982a; Shepard, 1982). These three dimensions present us with a 2 x 2 x 2 array of ways in which pitches might be presented in a stimulus and encoded into mental representations: Pitch Material non-tonal or tonal, Pitch Reference absolute or relative, and Octave Equivalence absent or present. Table 1 outlines that array, including suggestions for terms denoting the eight combinations of features and listing some closely related psychological processes. Two of the terms seem to conform to common usage. *Chroma*, as that aspect of pitches that tones an octave apart have in common, would appear in its most general application to be non-tonal and absolute in its frame of reference and to involve octave equivalence. *Tone Height* would appear to share all those properties except octave equivalence. The other terms in Table 1 are not presently in common usage, but are simply my own suggestions.

Two suggestions pertain to pitch representations that are non-tonal and have a relative pitch reference. *Pure Interval* encoding refers to the case where octave equivalence is not involved. Such pitch coding means simply encoding interval sizes and seems very close to the results of encoding in Deutsch's (1969) interval-encoding channel. When octave equivalence is involved such a representation involves encoding *Interval plus Octave Equivalence*.

Among the terms for pitch representations that involve a tonal framework, I propose *Tonal Chroma* for representations where the framework is anchored to an absolute pitch level and octave equivalence applies. The ability to name pitch chromas of arbitrarily selected tones (absolute pitch) would seem to depend on this type of representation, since such judgments are often subject to octave-level confusions. Where octave equivalence is not involved then the representation of pitch corresponds to Tone Chroma plus what is generally called Octave Level; that is, Tone Height expressed in a tonal scheme. Intervals described within a key, in what is called a *fixed-do* system of *solfège*, would encode such pitches. The set of such pitches would constitute what I have called elsewhere the "tonal material" of a culture's music (Dowling, 1978a, 1982c). Here I have been describing these features in terms of sets of pitches, but an equivalent account in terms of interval sets could also be given and might be useful for some purposes. The main difference in a pitch-encoded and an interval-encoded representation is that the former is not defined for particular single pitches. However, any pitch in a tonal interpretation invokes psychologically and musically the implicit interval set of the tonal scale of which it is a part, and so the conceptual difference between pitch and interval representations tends to fade.

With a relative reference point for pitch we move into the area of pitch representation that would be useful for melodic representation independent of particular key. *Scale Step* refers to pitches as they might be encoded in a *movable-do* system, defined simply by their interval relations to other members of the tonal scale set. Such a representation might be useful in the recognition of transpositions, since interval patterns remain constant across transposition and are independent of octave level. *Scale Function* refers to the octave-equivalent representation of scale steps; for example, the seventh degree of the scale – the leading tone – tends upward no matter which octave or key it occurs in.

One reason we study the recognition of distorted melodies is to isolate the features that are important in melody recognition generally, and to find out how those features are used in perception and memory. Octave-scrambled melodies specifically preserve the chromas of pitches of the original, but randomize tone height and destroy interval pattern. The fact that in the absence of any other information octave-scrambled versions of familiar melodies are hard to recognize (Deutsch, 1972; Dowling & Hollombe, 1977) suggests that melody recognition does not involve coding a test melody as a list of chromas (that is, applying octave equivalence) and then comparing that list with comparable lists in memory. On the contrary it suggests that melodic interval pattern is important to recognition; perhaps because, as noted above, interval pattern remains invariant through transposition.

Another way interval pattern might be important to recognition of octave-scrambled melodies is in providing information describing melodic contour. Melodic countour has been shown to be important generally in melody recognition. Contour-preserving distortions of familiar melodies (presented within one octave) are recognized at much better than chance levels (White, 1960; Dowling & Fujitani, 1971). Dowling and Hollombe (1977) and Idson and Massaro (1978) showed that when contour information is included recognition of octave-scrambled melodies improves markedly. That is, a test melody that preserves both the contour and the chromas of the original is recognizable at much better than chance levels, even though the interval pattern and tone-height consistency of the original have been destroyed.

Table 2
Proportions of Recognitions of Familiar Tunes and Distortions Preserving Contour and/or Chroma in Previous Experiments

	Condition			
Experiment	Original	Contour plus Chroma	Contour only	Chroma only
White (1960)	.94	–	.74	–
Dowling & Fujitani (1971)				
Expt 2	.99	–	.59	–
Deutsch (1972)	1.00	–	–	.12
Dowling & Hollombe (1977)				
Expt 1-2	.92	.66	–	.27
Idson & Massaro (1978)				
Expt 1-4	.86	.82	.65	.45
Kallman & Massaro (1979)				
Expt 1-2	.92	.66	.11	.06
Massaro et al. (1980)				
Expt 1 (day 3)	.92	.89	.69	.06
Expt 2 (day 3)	.74	.68	.53	.33
Mean Decrement from Original		−.13	−.34	−.68

Previous Results

Table 2 summarizes the results of those and several other studies that compare the effects of retaining chroma, contour, or both in octave-scrambled distortions of familiar melodies with recognition of undistorted originals. Recognition has typically been relatively good when both contour and chroma information have been present, somewhat worse with only contour information present, and worse still when only chroma information was present.

White used computer-generated complex tones. The value reported for White (1960) under "contour only" is the mean in his six-note presentation condition for all distortions that were likely to preserve contour. White used ten familiar tunes and presented them with intact rhythms. Dowling and Fujitani (1971) used complex tones to present two phrases of five tunes that had the same rhythmic pattern. Deutsch (1972) used pure tones to present four phrases of one tune with rhythm intact. Dowling and Hollombe (1977) used complex tones to present three same-rhythm melodies in one experiment and ten different-rhythm melodies in the other. Performance with chroma-only melodies was somewhat better in the latter case. Dowling and Hollombe also found recognition of chroma-only, but not contour-plus-chroma, octave-scrambled melodies to be positively related to musical experience. Idson and Massaro (1978) demonstrated that recognition performance with contour-only octave-scrambled melodies fell between performance with chroma-only distortions and distortions that preserved both contour and chroma. Idson and Massaro used pure tones to present one or two phrases of five tunes that differed in rhythmic pattern, but for which longer note durations were represented by repeated notes. Subjects had to decide which melody had been presented on each trial. Idson and Massaro used 700 trials spread over two days. They included both within-octave and octave-scrambled contour-only stimuli, but that variable had little effect.

Kallman and Massaro (1979) used three melodies differing in rhythm and presented by pure tones. They used a single-trial identification task, and included octave-scrambled contour-only distortions. Under those conditions recognition of all three types of octave-scrambled distortions decreased markedly relative to recognition of original versions, compared with the results of Idson and Massaro. Massaro, Kallman and Kelly (1980) returned to the forced-choice method of Idson and Massaro, using novel six-note melodies presented by pure tones. In two experiments they used different sets of four melodies. Subjects had one day for learning the original versions of the melodies followed by three test days of 200 trials each. The results of the third test day are included here. Like Idson and Massaro, Massaro *et al.* found recognition of contour-plus-chroma distortions to be relatively good. Contour-only recognition was poorer, and recognition of chroma-only distortions was low but highly variable.

It is clear from Table 2 that in spite of the wide variety of procedures and the differences between pure and complex tones the results of these experiments converge on a common ordering of difficulty for recognizing the various distortions: contour-plus-chroma, contour-only, and chroma-only, in descending order. This order is reflected in the pattern of mean decrements from recognition levels of originals shown at the base of the columns. Note that two distinct types of result occurred when originals and contour-plus-chroma octave scramblings were contrasted in the same experiment. Where there were many trials and a small, known set of stimuli, performance with contour-plus-chroma distortions was almost as good as with originals (Idson & Massaro, 1978; Massaro *et al*., 1980). Where there were few trials and an open-ended set of stimuli, performance with contour-plus-chroma distortions was markedly worse (Dowling & Hollombe, 1977; Kallman & Massaro, 1979), and I consider reasons for that below. There seems to be no general explanation to be found in differences of method for variations in recognition of contour-only and chroma-only stimuli, though it seems likely that studies with many trials and small stimulus sets involved particular confusions among the stimuli and induced specific strategies that affected performance.

Previous Theories

Deutsch (1969, 1982) proposed a two-channel model for melody recognition according to which a melody is encoded in separate, parallel channels: as a sequence of logarithmic interval sizes between successive tones, and as a sequence of absolute chromas. In this view interval encoding provides for the recognition of transpositions and chroma encoding provides for the performance of tasks relying on octave equivalence (for example, recognition of chord inversions). Deutsch (1972) proposed that performance in recognizing chroma-only octave-scrambled melodies is difficult because the results of interval encoding, and not chroma encoding, are of primary importance in the recognition of familiar melodies. When a melody is heard the listener does not use the abstracted chroma values of its notes in searching memory. With octave-scrambled melodies contour and interval information is absent and the listener cannot retrieve the memory. In other words, the set of chromas alone is not an adequate retrieval cue for a familiar tune. Octave equivalence does not function automatically in the recognition of octave-scrambled familiar melodies.

According to Deutsch's theory, better-than-chance performance in recognizing chroma-only octave-scrambled melodies should be impossible without additional cues. Deutsch (1978, 1982) suggested that in those cases where recognition of octave-scrambled melodies was better than chance it was because some cue other than the ordered set of chromas was providing for tentative retrieval from memory, generating an hypothesis that could be tested against the stimulus for a match of chromas. The additional cue could arise from any of several sources. Contour information would serve, leading to relatively good performance on contour-plus-chroma items as shown in Table 2. A limited set of stimuli could narrow the range of hypotheses to be tested, as in Idson and Massaro (1978) and Massaro *et al.* (1980). The better-than-chance performance obtained by Dowling and Hollombe (1977) with chroma-only stimuli would on this account be attributable to the explicit rhythmic information provided in that study.

A second theory, an elaboration of Deutsch's, was proposed by Idson and Massaro (1978) to explain the good performance they obtained with contour-plus-chroma stimuli. Idson and Massaro suggested that interval information might well be encoded in the chroma channel by a process that took advantage of octave equivalence. They proposed that intervals might be encoded directly on the chroma circle described above, using a bottom-up process acting on the test stimulus itself. Descending and ascending intervals would be represented as clockwise and counterclockwise rotations around the circle. Intervals greater than an octave are rare in familiar tunes. The large intervals of octave-scrambled melodies would be represented as rotations in semitones *modulo 12*; that is, they would be replaced with intervals smaller than an octave that preserved the chromas of the pitches forming them. A skip up from a C to the D in the third octave above, a skip of +26 semitones, would be represented as the interval from C to D around the circle, or +2 semitones. A skip from C down to the second G below, −17 semitones, would be represented as the interval of −5 semitones around the circle.

There are two ways in which the evidence outlined in Table 2 supports Idson and Massaro's theory that intervals are encoded directly from the octave-scrambled stimulus. First, the recognition of chroma-only octave-scrambled melodies should not be impossible, since as Idson and Massaro point out, on the average half the intervals of such stimuli will be correct. Second, contour-plus-chroma items should be easily recognized, since they contain all the relevant melodic information. This was the case in Idson and Massaro (1978) and Massaro *et al.* (1980). Problems for this theory arise from the experiments of Dowling and Hollombe (1977) and Kallman and Massaro (1979) where contour-plus-chroma performance was definitely worse than recognition of originals, though of course that decrement could arise from the operation of a less-than-perfect octave-generalization mechanism. Further, as Deutsch (1982) noted, the two studies in which relative contour-plus-chroma performance was best used small stimulus sets thay may have aided performance in the contour-plus-chroma condition. At best we are left with ambiguous support for the process of encoding intervals into chroma sets directly on the chroma circle. Nevertheless, the conversion of directional intervals to chromas via the chroma circle is a potentially useful process that could play a somewhat different role in a revised theory.

New Theoretical Proposal

The results of Idson and Massaro (1978), Massaro *et al.* (1980), Dowling and Hollombe (1977), and Kallman and Massaro (1979) are all compatible with Deutsch's notion of hypothesis testing. In fact, hypothesis testing is the best explanation for Dowling's (1973) result that listeners informed of the title of a familiar tune could discern it in the midst of interleaved extraneous notes. According to that theory the title cue allowed listeners to retrieve the memory of the melody, perhaps coded in terms of the Scale Steps described in Table 1. Listeners used the memory record to generate an ordered set of tonal chromas, in the appropriate key, for the target melody. They then tested the generated chroma set against the test melody, and if a sufficient number of pitches matched, they reported hearing the target. At this point the question is left open as to whether octave matches occur due to octave-equivalence processes operating on the generated melody representation or on the octave-scrambled stimulus.

If testing of comparison stimuli involves the testing of the literal match of the internal representation and the stimulus, then whatever the nature of the stored memory record of a melody—ordered set of scale steps, ordered interval set, or contour—reconstruction of a representation of the melody as an absolute tonal chroma set in a particular key must occur. Relative scale steps must be expressed as absolute chromas and intervals must be anchored to a tonic and translated into absolute chromas (perhaps by mapping onto the chroma circle as in Idson and Massaro's model). As noted above there is little conceptual difference between characterizing a melody as a set of relative scale steps or as a set of intervals among them. If the memory of a melody consisted of a contour, an absolute chroma set could be generated by anchoring the contour to the appropriate diatonic scale. The origin of the melody on the scale and the location of those relatively rare intervals greater than one diatonic step would need to be marked in memory, as Dowling (1978a) suggested.

The common feature in all of the preceding processes by which hypothesis testing might be carried out is that whatever the form of a melody in memory, it must be translated into a tonal chroma set for testing. (At least this seems more likely for familiar tonal melodies than, say, translation into pitch heights.) This is absolutely necessary in the case of recognition of temporally interleaved melodies (Dowling, 1973, Note 1). In those stimuli the interval pattern made no sense at all and experienced listeners were baffled by their identity even after many repetitions. That is, it seems unlikely that listeners could ever recover targets from the interleaved melodies by some bottom-up process of analysis on the stimuli themselves, but rather require additional cues. It also seems unlikely that bottom-up analyses of chroma-only octave-scrambled stimuli could lead to identification. The top-down hypothesis-testing approach gives a viable alternative account.

Experiments 1 and 2 tested an implication of the hypothesis-testing theory. If this theory were correct, then it should be possible for listeners to verify the match of a chroma-only octave-scrambled melody to an unscrambled melody cue they have just heard, or to a candidate retrieved from memory on the basis of its title. In Experiment 1 listeners heard a couple of phrases of a folk melody, familiar or unfamiliar. Then they heard a chroma-only octave-scrambled version of either the target melody or a lure. The listeners' task was to decide whether the comparison melody was the same as the original. In Experiment 2 the melody cue was replaced with the title of a familiar tune, and so listeners first heard the title and then the octave-scrambled test stimulus.

I included familiar and unfamiliar melodies in Experiment 1 to explore the role of memory in the hypothesis-testing process. The melody cue provides in itself an appropriate tonal chroma set for testing against the comparison stimulus, without reference to memory. If subjects were simply to use that explicit chroma set in testing the comparison, then there should be no difference in performance between familiar and unfamiliar conditions. A difference between performance with familiar and unfamiliar melodies would indicate the involvement of memory in the testing process.

The experiments are introduced by a General Method section describing aspects of method shared by all three experiments.

Experiments

General Method

Subjects. The subjects were volunteer graduate and undergraduate students at the University of Texas at Dallas who served in group sessions. Undergraduate students received course credit for participation. Musical experience was defined as lessons on an instrument or voice, and was dichotomized with

2 yr. or more classified as "experienced," and less than 2 yr. as "inexperienced." The mean years experience of the experienced subjects was approximately 5 yr. The experienced group was thus only moderately experienced, not having nearly so much training as professional musicians. The mean age of the subjects was 31.6 yr. and the ratio of males to females was approximately .67.

Stimuli. The stimuli for Experiments 1, 2, and 3 were played on a freshly tuned Steinway piano. The stimuli were played at half speed and recorded on reel-to-reel tape at 9.5 cm/sec. The stimuli were then played back at 19.0 cm/sec and rerecorded on cassette tape for presentation to subjects. The subjects thus heard a recording which was twice as fast and one octave higher in pitch than the version originally recorded. All the following stimulus parameters refer to the stimuli heard by subjects. All recording was done with high-quality tape (Scotch 208 Low-Print/Low-Noise Mastering Tape and Maxell UD-XL II cassette tape) and equipment (SONY ECM-200 condenser microphones, and TEAC A-1200U and CX-315 recorders). Subjects listened to stimuli presented over loudspeakers at comfortable levels. Stimuli were presented at .83 sec per quarter-note beat, where a quarter note represents the predominant note duration in each stimulus. There was an interstimulus interval of 3.33 sec, and an intertrial interval of 6 to 8 sec, or longer in conditions where subjects needed time to write a song title. Fundamental frequencies of scrambled melodies lay within a 6-octave range from a C of 65.5 Hz (fundamental frequency) to a B of 3943 Hz. Successive pitches in octave-scrambled stimuli never fell within the same octave. Melody cues were presented within a middle octave and typically began on the C (524 Hz) or the F (354 Hz) above middle-C.

Procedure. The experimenter told the subjects they would hear pairs of melodies. The first melody of each pair would be played "straight," with all the notes in one octave. The second melody of each pair might have its notes scrambled among six octaves. The subject's task was to decide whether the second melody contained the same notes as the first, setting aside the fact that the notes had been rearranged. Several examples relevant to the conditions of the particular experiment were presented and explained, and repeated if necessary. Subjects responded on a single, numbered answer sheet using a four- or six-category scale ranging from *sure same* to *sure different*, depending on the experiment.

Data Analysis. Since the response scale changed across the experiments different types of data summary were used. The proportions of *yes* responses (ratings of 3 or 4) on the four-point scales, and the mean ratings of stimuli on the six-point scales, were subjected to analysis of variance (ANOVA). Proportions of responses to targets and lures at each criterion level on the category scale were used to plot receiver operating characteristics (ROCs) for each subject for each stimulus condition. Areas under the ROC were calculated and can be taken as estimates of unbiased proportion correct where chance is .50 (Swets, 1973). For consistency of comparison across experiments area scores are presented in the data tables, and ANOVAs on those areas are reported. I report the results of the ANOVAs on proportions or ratings where they differ qualitatively from the area ANOVAs.

Experiment 1

Method

Subjects. Fifteen subjects served in Experiment 1, with seven inexperienced and eight experienced.

Stimuli. On each trial of the experiment the subject heard an original version of a melody played within one middle octave, followed by a comparison melody which was either a target or a lure. Stimuli consisted of approximately the first 16 beats of each melody, and had a mean duration of 12.7 sec. Targets were chroma-only octave-scrambled versions of originals; lures were octave-scrambled versions of something else. Comparison melodies were always presented with the same rhythm as the original melody in the trial. There were two conditions: familiar and unfamiliar. The order of trials within each condition was randomized.

There were 11 melodies in the familiar condition: "Frére Jacques," "Adeste Fideles," "Jingle Bells," "Froggy Went a'Courting, " "I've Been Working on the Railroad," "Good King Wenceslaus," "Oh, Susannah," "Old MacDonald," "Red River Valley," "On Top of Old Smokey," and "Happy Birthday." The comparison melody for the first five of those melodies was a target. Comparison melodies for the remaining six were lures. For the first three of the six lures the pitches of the lures were from three other familiar melodies: "Mary Had A Little Lamb," "Yankee Doodle," and "Twinkle, Twinkle Little Star," respectively. For the remaining three lures the comparisons contained randomly selected pitches. Type of lure (familiar vs. random pitches) had no effect on performance and will not be considered further.

The ten melodies in the unfamiliar condition were drawn from Sharp and Karpeles's (1968) collection of Appalachian folk songs: "William Hall," "The Nightingale," "The Cherry Tree Carol," "The Chickens They Are Crowing," "The Death of Queen Jane," "The Wife Wrapt in Wether's Skin," "Sally Anne," "The Cruel Mother," "Going to Boston," and "Will You Wear Red." The first five were tested with targets, and the remaining five with lures from the same source (presented as in the familiar condition): "The Sally Buck," "The Two Crows," "Our Goodman," "The Two Sisters," and "Green Bushes."

Procedure. All subjects served in the two conditions. Seven subjects (blindly selected) heard the familiar condition first, and the other eight the unfamiliar condition first. Subjects first listened to two examples: the first was an original-original pair and the second was an original-scrambled pair with a familiar target. Subjects responded to the 21 trials on a single answer sheet using a four-category confidence-level scale. Subjects were asked to identify the melody on each trial of the familiar condition following their recognition responses. Subjects wrote the title, words or type of melodies they recognized. Responses that unambiguously identified the song were scored as correct; for example, words such as "dormez vous" for "Frére Jacques," or an alternate title such as "The Eyes of Texas" for "I've Been Working on the Railroad." Correct identifications of the originals ranged from 0 to 100% with a mean of 71%. The only originals identified at less than 87% correct were: "Froggy Went a'Courting" (0%), "Good King Wenceslaus" (40%), "Oh, Susannah" (33%), "Red River Valley" (73%), and "On Top of Old Smokey" (60%).

Table 3
Area Under the ROC[a] for Octave-Scrambled Melodies in Experiments 1 and 2

		Condition	
		Familiar	Unfamiliar
Experiment	Cue		
1	Melody	.81	.73
2	Title	.83	—

[a] Receiver Operating Characteristics

Results

The results of Experiment 1 are shown in the first row of Table 3. Performance was much better than the chance level of .50 in both conditions. I performed a three-way ANOVA on areas under the ROC with two experience levels x two orders of conditions x two conditions. The main effect of condition was significant, $F(1, 11) = 8.23, p < .02$, with familiar melodies easier. The interaction of Order x Condition was significant, $F(1, 11) = 9.71, p < .01$, with the unfamiliar condition much easier when it followed the familiar condition (.79) then when it came first (.68). That is, when the unfamiliar condition came second it was about as easy as the familiar condition. No other effects were significant.

Discussion

Clearly listeners were able to recognize familiar and unfamiliar melodies in chroma-only octave-scrambled form when they had just heard original versions of those melodies. The task was easier with familiar melodies, but practice doing the task with familiar melodies led to marked improvement with unfamiliar melodies. The fact that performance was better with familiar melodies indicates that even with the appropriate tonal chroma set present in the cue stimulus subjects nevertheless retrieved information from memory that they used in evaluating the comparison stimulus. To the degree that information from memory was important to that testing process, performance should be the same with familiar melodies whether or not the melody itself was actually presented as a cue. Experiment 2 explored this possibility by replacing melody cues with familiar tune titles in the same paradigm as Experiment 1.

Experiment 2

Method

Subjects. Ten subjects served in Experiment 2, with five inexperienced and five experienced.

Stimuli. There were eight trials. Stimuli were the same as those of the familiar condition of Experiment 1 except for the omission of the three trials with familiar lures.

Procedure. The procedure was closely parallel to that of Experiment 1, except that a trial consisted of presentation of a tune title followed by a chroma-only octave-scrambled melody that was either a target (matching the title) or lure (mismatching). Titles were the same as in the target trials and random-lure trials of Experiment 1. Lures were the random sequences used in Experiment 1. Subjects responded using a four-category confidence-level scale.

Results

The results of Experiment 2 are shown in Table 3. There was no effect of experience. Performance was comparable to that in the familiar condition of Experiment 1. I ran a two experience levels x three conditions ANOVA on the results of the first block of Experiment 1 together with the results of Experiment 2, since subjects in those three conditions had followed virtually the same procedure. Only the main effect of conditions approached significance, $F(2, 19) = 2.26$, $p = .13$, with mean performance in the three conditions of .79 (familiar, melody cue); .68 (unfamiliar, melody cue); and .83 (familiar, title cue).

Discussion

The results of Experiments 1 and 2 supported hypothesis-testing as an explanation of listeners' success in recognizing chroma-only octave-scrambled melodies, since listeners provided with explicit hypotheses via either melody or title cue performed well above chance on that task. Memory was involved even when the task included explicit melody cues, shown by the fact that performance was better with familiar than with unfamiliar melodies, and that performance remained constant when familiar melody cues were replaced by title cues. Even inexperienced listeners knew the melodies well enough to perform well on the task. The involvement of long-term memory in a task in which it logically need not be involved is interesting. It suggests that instead of simply holding the cue melody in short-term storage until the comparison melody was presented, subjects may have encoded it in some manner and then retrieved features of it for comparison.

This involvement of memory led me to a third experiment exploring the process by which octave-scrambled melodies are evaluated. Experiment 3 was like the unfamiliar condition of Experiment 1, but included two new variables. First, the design included trials requiring discrimination of exact repetitions of targets from different-contour comparison melodies. Performance on those trials was contrasted with discrimination of chroma-only octave-scrambled targets from different comparisons (the task in Experiment 1). Dowling and Fujitani (1971, Expt 1) obtained near-perfect performance on the former task, and suggested that subjects were simply holding the pitches of each initial melody long enough in immediate memory to make the comparison. To the extent that performance departs from near-perfect when this task is included in the same session with the octave-scrambled recognition task, we can conclude that the latter task is leading subjects into encoding strategies that are less than optimal for the simpler task. Those strategies would presumably involve more elaborate encoding of melodies than simple retention of the pitch sets, which strategies aid in the performance of the more difficult task.

The second variable I included in Experiment 3 involved the use of tonal vs. atonal stimuli. *Tonal* meant that a melody was constructed using the seven pitches of a diatonic major scale, in this case C-major. *Atonal* meant that a melody was constructed using the entire set of twelve pitches in the chromatic scale, including pitches that departed from any one diatonic scale, major or minor. Of course, no sequence of seven pitches could be absolutely atonal in the sense of having no interpretation in any tonal framework with modulations from one key to another allowed. Therefore *atonal* here means "relatively atonal," as having no simple interpretation within a single tonal key.

The reason for including tonal vs. atonal as a stimulus dimension was that there is considerable evidence that the pitches of tonal melodies are easier to encode and recognize (Dewar, Cuddy & Mewhort, 1977, Expt 1; Dowling, 1982a). Thus effects of tonality would indicate differential success of encoding and hence converge with the evidence of Experiments 1 and 2 indicating involvement of long-term memory processes. It seemed plausible to expect that if there were effects of tonality they would be more pronounced among experienced than inexperienced subjects, since in previous studies of melody recognition experienced subjects had been more likely to use the tonal scale framework in solving the task. For example, experienced subjects found it easier than inexperienced to discriminate between tonal and atonal melodies having the same contour (Dowling, 1978; Bartlett & Dowling, 1980).

In a recent study in our laboratory (Dowling, 1982b) experienced subjects used a tonal scale-step encoding strategy in spite of the fact that it led to poorer performance than the simpler encoding strategy used by inexperienced subjects. In that study six-note melodies were embedded in chordal contexts that defined the melodies as built around either the first degree of the scale (do) or around the fifth degree of the scale (sol). Subjects had to remember the melodies across time intervals filled with other trials, discriminating transposed targets from lures having one altered pitch. The context either remained constant relative to the test melody (that is, either do-do or sol-sol); or changed (that is, do-sol or sol-do). Inexperienced subjects performed equally well whether the chordal context shifted or not. Experienced subjects performed slightly better than inexperienced on constant-context trials. However, when context shifted the experienced subjects' performance fell to chance. Experienced subjects were relying much more heavily than inexperienced on representations of target melodies encoded in terms of the tonal scale framework. When a shift of context altered the tonal scale-step interpretation of a test melody it left them without an accurate means of verifying its identity.

Considerations like these led me to think that some sort of interaction might appear in Experiment 3 between experience and the tonal-atonal dimension. This provided for further exploration of Dowling and Hollombe's (1977) result that experienced subjects performed better than inexperienced on recognition of tonal chroma-only octave-scrambled melodies. Experiment 3 tested whether that superiority would obtain with both tonal and atonal, or only with tonal, melodies. That is, it tested whether musical experience confers a general advantage in tasks requiring the application of octave-equivalence relationships in identifying a melody, or whether that advantage is restricted to tonal stimuli.

All the melodies in Experiment 3 were novel, being randomly generated. Experiment 3 used a cued recognition task and resembled closely the Unfamiliar condition of Experiment 1.

Experiment 3

Method

Subjects. Twenty-one subjects served in Experiment 3 with eleven inexperienced and ten experienced.

Stimuli. All melodies were seven notes long, and followed the rhythmic pattern of the first phrase "Yankee Doodle" and "Good King Wenceslaus." The melodies began on C and were either tonal or atonal. Each trial was introduced by a randomly generated melody, presented as in Experiment 1. Tonal melodies were in the key of C major and had the following distribution of diatonic interval sizes: P(± 1 diatonic step) = .30, P(± 2 diatonic steps) =.60, P(± 3 diatonic steps) = .10. (A diatonic step can be either 1 or 2 semitones, depending on where it falls in the diatonic major scale.) Atonal melodies began on C and were generated randomly using the following distribution of interval sizes: P(± 1 semitone) = P(± 5 semitones) = .10, P(± 2 semitones) = P(± 3 semitones) = .30. P(± 4 semitones) = .20; with the constraint that the sequence contain pitches that caused it to deviate from any single diatonic scale. The expected interval sizes in tonal and atonal melodies were 3.09 and 2.90 *semitones, respectively.*

There were 64 trials, randomized in two different counter-balanced blocks of 32. There were eight trials each of eight types defined by a 2 x 2 x 2 design: Same vs. Different comparison stimulus; Repetition-comparison vs. Scrambled-comparison condition; and Tonal vs. Atonal melody. The comparison melody on Same trials was a repetition of the target in the repetition condition and a chroma-only octave-scrambled version of the target in the Scrambled condition. On Different trials the comparison was a version of a completely different melody generated in the same way as the target. Comparison stimuli in the repetition-comparison condition were presented in the same octave as the initial stimuli in the trials.

Procedure. Six examples introduced the session. There were six unscored buffer trials at the start of the test, so that from the subjects' point of view there were 70 trials in the experiment. Subjects responded using a six-category response scale.

Results

The results of Experiment 3 are shown in Table 4. Performance was better than chance in all the cells. In the 2 experience levels x 2 conditions x 2 tonalities ANOVA there were significant main effects of condition, $F(1, 19) = 31.31, p < .001$, with repetition comparisons easier (.80) than scrambled (.63); and of tonality, $F(1, 19) = 9.49, p < .01$, with tonal easier (.74) than atonal (.69). There was a significant interaction of Tonality x Experience, $F(1, 19) = 4.71, p < .05$, in which experienced subjects performed especially well (.77) on the tonal trials. The only other significant effect was the Experience x Condition x Tonality interaction shown in Table 4, $F(1, 19) = 6.49, p < .02$. Both groups produced similar performance in the repetition condition. In the scrambled condition experienced subjects performed better with tonal stimuli than with atonal, while the inexperienced subjects did not. In an ANOVA on the scrambled condition alone the interaction supporting that conclusion was significant, $F(1, 19) = 8.07, p < .02$. The difference in inexperienced subjects' performance between tonal and atonal scrambled stimuli was not significant by a t-test.

Table 4
Area Under the ROC for Repeated and Octave-Scrambled Novel Melodies Cued by Original Melody in Experiment 3 and 4

	Condition			
	Repetition		Scrambled	
Group	Tonal	Atonal	Tonal	Atonal
Experiment 3				
Inexperienced	.84	.75	.59	.64
Experienced	.85	.78	.70	.57
Mean	.84	.77	.64	.61
Experiment 4				
Inexperienced	.84	.76	.56	.61
Experienced	.84	.82	.69	.55
Mean	.84	.80	.64	.57

The only qualitatively different result shown by the experience x condition x tonality x item type (target vs. lure) ANOVA on confidence-level ratings was in a significant Experience x Condition, $F(1, 19) = 4.80$, $\varrho < .05$, in which inexperienced subjects showed a response-bias shift toward caution in the scrambled condition while experienced subjects did not.

Discussion

As in Experiments 1 and 2 memory processes were clearly involved in the evaluation of comparison stimuli that followed melody cues. Experienced and inexperienced subjects performed about equally well in the repetition condition of Experiment 3. Both groups performed better discriminating literal repetitions from lures when those were tonal than when they were atonal. That would not have been the case if subjects were simply storing the pitch set in immediate memory. The fact that performance was better with tonal stimuli shows that subjects were engaging in some processing of the stimuli on which the well-learned tonal scale pattern conferred some advantage.

It is surprising that performance was not better on the repetition recognition task, since when the task was presented alone subjects performed extremely well on it, even with atonal melodies (Dowling & Fujitani, 1971). Performing the chroma-only octave-scrambled recognition task concurrently apparently led subjects into more elaborate strategies than those used by Dowling and Fujitani's subjects—strategies that were not optimal for the repetition-recognition task when presented alone. It seems likely that here subjects used some form of encoding that took account of tonal scale steps, leading to superior performance on tonal trials in the repetition condition.

In the scrambled condition the advantage for tonal stimuli disappeared for the inexperienced subjects, but increased for experienced subjects. Experienced subjects performed no better than inexperienced with atonal octave-scrambled melodies. This agrees with the results of Dowling and Hollombe (1977) who found that experienced subjects performed better than inexperienced with chroma-only octave-scrambled melodies, and shows that experience is helpful only where tonal encoding can be used. Both groups would seem to have used a tonal encoding system equally well with the cue stimuli, as tonality affected repetition recognition equally for both groups. The selective advantage experienced subjects had with tonal octave-scrambled melodies can reasonably be attributed to greater facility in interpreting octave equivalences by translating scrambled melodies into tonal chromas or scale functions. Unlike the result of Dowling (1982b) where performance suffered from such a strategy when tonal context was changed, here it led to better performance.

There was one flaw in Experiment 3 that became apparent after it had been completed; namely, that it would be possible to perform the cued-recognition task with better-than-chance accuracy on the basis of literal pitch matches alone, without using octave-equivalence. This argument notes that the pitches of the comparison stimuli in Experiment 3 were distributed thoughout six octaves, *including the octave of the cue stimulus.* Same comparisons would share more pitch chromas with cue stimuli than Different comparisons, and that would be true to some extent of pitches within the octave of the cue. Thus listeners could perform better than chance just by noticing shared pitches in the cue-comparison pair. The obvious control is to exclude pitches in the comparison stimuli from the octave of the cue, and this was done in Experiment 4. Experiment 4 also provided the opportunity to produce stimuli more precisely by means of computer, but in its essentials was virtually identical to Experiment 3.

Experiment 4

Method

Subjects. Thirteen subjects served in Experiment 4, with five inexperienced and eight experienced.

Stimuli. Timing and structure of Experiment 4 were the same as of Experiment 3, except that the interstimulus interval was 6.67 sec, the same time span as the cue. Cue stimuli were aligned to fall mainly into the octave between middle-C (262 Hz) and the C above (524 Hz). Melodic lines that tended upward started on middle-C; those tending downward started on the upper note. Octave-scrambled comparison stimuli had their pitches randomly assigned to four octaves: two above and two below this middle octave. Some cue stimuli extended beyond the boundaries of the middle octave, and on those trials the comparison stimuli avoided pitches within the range of the cue.

Stimuli were produced by a Commodore 64 computer using its 6581 sound generating chip, and recorded directly on tape. Stimulus tones had a sawtooth waveform with an onset ramp of 24 msec, a decay ramp of 48 msec settling at one-fourth the peak amplitude of the attack, and ending with a 6 msec release ramp initiated 670 msec after onset. As in the previous experiments time between onsets was 833 msec. Each trial was preceded by 1.67 sec with a warning beep at about 3950 Hz.

Procedure. Four examples introduced the session, and there were four unscored buffer trials, giving 68 trials to which subjects responded.

Results

The results of Experiment 4 are shown in Table 4 where they can be seen to closely parallel those of Experiment 3. Performance in all cells was better than chance. In the ANOVA there was a main effect of condition, $F(1, 11) = 35.10$, $p < .001$, as before. There was a significant Experience x Condition x Tonality interaction, $F(1, 11) = 9.39$, $p < .02$. The main effect of tonality was not significant, and the effects of the interaction appeared in both the repetition and scrambled conditions. Experienced subjects performed about as well with atonal as with tonal repetitions with these more precise stimuli. The pattern of performance in the scrambled condition was the same as in Experiment 3, with inexperienced subjects performing at least as well with atonal as with tonal stimuli, but experienced subjects showing a large difference. As in Experiment 3 the 2 x 2 ANOVA of the pattern in the scrambled condition showed a significant interaction, $F(1, 11) = 4.85$, $p < .05$.

General Discussion

We can now turn to the more general question of the likely form of memory representations of melodies, taking into account the studies just described as well as converging evidence from other studies. One way to pose the question is to ask where within the framework outlined in Table 1 viable candidates are likely to fall. Therefore I will consider whether such representations are likely to embody octave equivalence, have absolute or relative pitch reference, and use a tonal framework. Before proceeding I should note that the melody-encoding processes that I am proposing are performed by listeners at a subconscious level by the brain. Only the results of processing, such as the impression that one is familiar with a melody just heard, are reported by the underlying brain processes to the conscious levels of mental functioning. Even experienced subjects in studies like Experiments 3 and 4 feel that they are performing at chance, and are surprised to learn that their information-processing equipment is working much better than they had supposed. If the encoding processes I propose were fully accessible to consciousness then our moderately experienced subjects could outperform the typical music school freshman at melodic dictation.

Deutsch's (1972) demonstration that presenting only the chromas of a melody is an insufficient cue for identification strongly suggested that melodies are not represented in memory as chroma or scale-function lists embodying octave equivalence. There is further evidence. If melodies were originally encoded in octave-equivalent form then repeated presentation of a melody in octave-scrambled form should lead to improved recognition performance over a single-presentation condition. Deutsch (1979) showed that the reverse was true. Also, chroma or scale-function lists would seem to be too ambiguous as memory representations to provide for rapid and accurate retrieval. As an example consider the scale-function list "sol-do-mi-sol" (scale degrees 5-1-3-5; or in C major the pitches G-C-E-G) sounded with the rhythm quarter-quarter-quarter-half. With the contour [+ + +] (up-up-up) it becomes the start of the song "I'm Going To Leave Old Texas Now." With the contour [− + −] it becomes reminiscent of the "Westminster Chimes" pattern. (In fact, so strong is the effect of contour that one has to pause an instant to remember that the latter uses the scale functions "mi-do-re-sol" — 3-1-2-5.) The contours [+

+ −], [− + +], and [+ − +] all lead to plausible but distinctly different melodies. The same chroma or scale-function list can serve as the basis for many different melodies. Therefore melodies are not likely to be represented in memory in a way that intrinsically embodies octave equivalence.

On the question of relative vs. absolute pitch reference the strongest evidence is that not only do listeners find it possible to recognize transpositions of familiar melodies, but they are typically unable to tell when a melody has been transposed from its previous presentation, provided that presentation was not too recent. However, encoding a melody into a relative pitch-reference form, such as scale steps, takes time. The most immediate forms into which melodies are encoded when first heard are a non-tonal absolute pitch representation (tone height) and contour, as Dowling and Fujitani (1971) suggested. Listeners perform almost perfectly recognizing even atonal melodies when literally repeated after a brief delay. Listeners use a contour representation in deciding whether an immediately presented transformation (for example, an inversion) of melody is accurate (Dowling, 1972). Inexperienced listeners sometimes use contour representations more effectively than experienced listeners (Dowling & Fujitani, 1971). And listeners confuse translations of contour involving changes of intervals with transpositions when those are presented immediately (Dowling, 1978a). More experienced listeners apparently perform scale-step encoding more quickly than inexperienced; for example, they are sometimes less confused than inexperienced listeners in the transposition-recognition task just described when tonal melodies are used (Bartlett & Dowling, 1980). Neither experienced nor inexperienced listeners are confused when there is a delay between initial presentation and test (Dowling & Bartlett, 1981). With sufficient time listeners move from reliance on a contour representation to a more accurate representation of pitch intervals, either as tonal scale steps or as pure intervals.

Regarding tonal representations, in Experiments 3 and 4 both groups appear to have been using tonal scale steps. However, more experienced listeners are more likely to use tonal scale step encoding than inexperienced. In the transposition recognition task with context shifts described above (Dowling, 1982b), inexperienced listeners were not confused by shifts of tonal context, suggesting non-tonal encoding. Both groups apparently use melody representations embodying relative pitch reference without octave equivalence: typically scale steps, but with inexperienced listeners sometimes using non-tonal interval representations.

These considerations strongly suggest in tasks like those used here listeners generate tone chromas from tonal scale-step or interval representations in memory in order to evaluate chroma-only test stimuli. Such memory representations cannot easily be accessed given only chroma information in a stimulus. Rather, retrieval from memory seems to require additional melodic contour and/or rhythmic contour information. Retrieval of a relevant memory representation via contour does not seem sufficient for the listener to report remembering the stimulus. The information from memory must be verified against the chromas in the stimulus. Only then does the listener recognize the test melody. This is true not only of octave-scrambled melodies in the present study, but also of melodies interleaved in time (Dowling, 1973) and of string quartet fragments presented with musical context (Dowling & Bartlett, 1981).

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